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ABSTRACT

This document is designed to help teachers deal with the changeover from the United States customary system to the metric system. This publication contains a brief introduction to the historical development of the metric system, tables of the International System of Units, and descriptions of everyday use of the metric system. Basic information needed for teaching metric measurement in length, area, volume, mass, and temperature is provided. (MP)

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METRIC MEASUREMENT

A Resource for Teachers

U.S. DEPARTMENT OF HEALTH, EDUCATION & WELFARE
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METRIC MEASUREMENT

A Resource for Teachers

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FOREWORD

In 1975, the U.S. Metric Conversion Act was signed into law. This act establishes a federal mechanism to coordinate the conversion to the metric system. During the sixty-fifth Texas Legislative session, a 12-member Metric Council was created within the Texas Industrial Commission. The Council's primary function is to investigate problems Texas will face during the transition to the metric system and to disseminate information about it.

In a matter of a few years, the metric system of measurement will be a part of every American's life. *Metric Measurement* is designed to help teachers, especially secondary mathematics teachers, deal successfully with the changeover from the U.S. customary system to the metric system.

Included in this publication are a brief introduction to the historical development of the metric system, tables of the International System of Units, and descriptions of everyday use of the metric system. The publication provides basic information needed for teaching metric measurement in length, area, volume, mass, and temperature.

M. L. Brockette
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INTRODUCTION

The history of measurement in the world is interesting and often quite colorful. It is not known how long human beings have been measuring, but it could be speculated that measuring in some form has taken place throughout human history. We certainly know that measurements have been made throughout recorded history.

Many of the early standards of measurement were probably based on parts of the human body. These standards, of course, were not uniform, since there was variation in the size of every person. As civilizations developed, various attempts were made to establish systems which would bring order and uniformity to measurement. However, many different systems and standards of measurement were developed throughout the world.

As the activities of the world became international, it was evident that a uniform system of weights and measures was not only desirable, but necessary. During the eighteenth century, scientists began to realize that they needed a uniform system of weights and measures for their work to progress.

In 1797 the metric system was created as a result of a study by France's famed Academy of Science. The Academy indicated that all forms of measurement should have something in common. The metric system accomplished this by relating length, volume, and mass. The unit of length was given the name "meter," derived for the Greek word "metron" meaning "a measure." The meter was to be represented by a physical standard constructed to equal "one ten-millionth of the distance from the North Pole to the Equator along the meridian of the earth running near Dunkirk in France and Barcelona in Spain." Volume and mass were to be derived from this base unit of length.

France made the usage of the metric system compulsory in 1840. As the years passed, other countries began adopting it, and in 1875, 17 countries, including the United States, signed the "Treaty of the Meter." This treaty established an International Bureau of Weights and Measures, with headquarters near Paris, for the purpose of coordinating the exchange of information about use and refinement of the metric system.

As more precise methods of defining measuring units have been developed, the General Conference of Weights and Measures has met to ratify improvements, which are then disseminated by the International Bureau of Weights and Measures. Scientists have learned, for example, that the shape of the earth is neither uniform nor unchanging. Hence, the definition of the meter, based on a meridian, was not accurate. In 1960 the General Conference adopted a new definition of the meter, together with an extensive revision and simplification of the entire system. The definition of the meter is highly technical and bases the length on a specific number (1 650 763.73) of the orange-red wave lengths of the krypton-86 atom.

The modernized metric system was named Le Systeme Internationale d' Unites (International System of Units), or SI. Additional improvements and additions to SI were made by the General Conference in 1964, 1968, and 1971.

THE INTERNATIONAL SYSTEM OF UNITS

The International System of Units (SI) includes seven basic physical quantities: length, mass, time, electric current, temperature, luminous intensity, and amount of substance.

Each physical quantity is represented by a "base" unit included in the following chart:

Base Units

Length	meter (m)
Mass	kilogram (kg)
Time	second (s)
Electric Current	ampere (A)
Temperature	kelvin (K)
Luminous Intensity	candela (cd)
Amount of Substance	mole (mol)

Other units can be derived mathematically from these base units as illustrated in the following charts.

Derived Units

(expressed in terms of base units from which they are derived)

area	square meter – m^2
volume	cubic meter – m^3
density	kilogram per cubic meter – kg/m^3
velocity	meter per second – m/s
acceleration	meter per second squared – m/s^2
luminance	candela per square meter – cd/m^2

Derived Units (expressed by special names)		
force	newton – N	$kg \cdot m/s^2$
pressure	pascal – Pa	N/m^2
work	joule – J	$N \cdot m$
power	watt – w	J/s
electric charge	coulomb – C	$A \cdot s$
electric potential	volt – V	W/A
frequency	hertz – Hz	l/s
electric capacitance	farad – F	$A \cdot s/v$
electric resistance	ohm – Ω	V/A
magnetic flux	weber – wb	$v \cdot s$
inductance	henry – H	$v \cdot s/A$
luminous flux	lumen – lm	$cd \cdot sr^*$
illumination	lux – lx	lm/m^2

*Certain units of the SI are assigned to a third class called "supplementary." These units are used to form derived units. This class currently contains two, purely geometrical units: the radian (rad), which is a plane angle unit, and the steradian (sr), which is a solid angle unit.

In the metric system prefixes are used to indicate units larger and smaller than a given base unit. The prefixes tell what the value of the new unit is. Each prefix represents a different power of 10, and it can be added to any of the basic or derived units. The following is a list of metric prefixes, along with their symbol, factor, and decimal meanings.

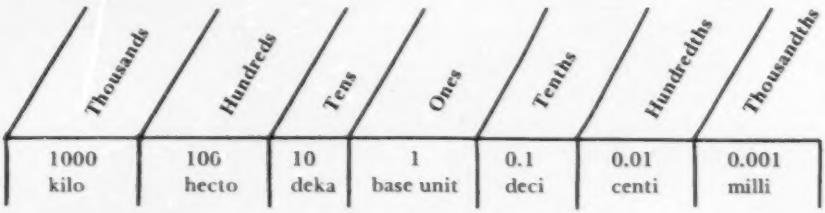
Prefix	Pronunciation (USA)	Symbol	Factor	Decimal
exa	ex'a (a as in about)	E	10^{18}	1 000 000 000 000 000 000
peta	as in petal	P	10^{15}	1 000 000 000 000 000
tera	as in terrace	T	10^{12}	1 000 000 000 000
giga	jig'a (a as in about)	G	10^{9}	1 000 000 000
mega	as in megaphone	M	10^{6}	1 000 000
kilo	as in kilowatt	K	10^{3}	1 000
hecto	heck'toe	h	10^{2}	100
deka	deck'a (a as in about)	da	10	10
deci	as in decimal	d	10^{-1}	0.1
centi	as in sentiment	c	10^{-2}	0.01
milli	as in military	m	10^{-3}	0.001
micro	as in microphone	μ	10^{-6}	0.000 001
nano	nan'oh (an as in ant)	n	10^{-9}	0.000 000 001
pico	peek'oh	p	10^{-12}	0.000 000 000 001
femto	fem'toe (fem as in feminine)	f	10^{-15}	0.000 000 000 000 001
atto	as in anatomy	a	10^{-18}	0.000 000 000 000 000 001

EVERYDAY USE OF THE METRIC SYSTEM

For ordinary usage, the meter, the liter (a non-SI unit), and the gram are of most concern. Similarly, the list of metric prefixes can be shortened considerably. The chart below indicates the commonly used prefixes.

kilo	one thousand	1000
hecto	one hundred	100
deka	ten	10
deci	one tenth	0.1
centi	one hundredth	0.01
milli	one thousandth	0.001

Notice the relationship of the prefixes with our decimal system of counting. This may be illustrated as follows:



By combining roots and prefixes, all the units of measurement needed can be derived.

LENGTH

The base unit for length is the meter. The meter is a little longer than one yard or about 39.37 inches. A standard meter stick is divided into 100 centimeters and 1000 millimeters. A millimeter is one-tenth of a centimeter.

A kilometer is 1000 meters long, which is a little more than a half mile. Long distances are measured in kilometers.

Length measurement may be expressed in various forms. An object which measures 26 centimeters may be expressed as 260 millimeters, 2.6 decimeters, or 0.26 meters. The relationships of 10 make it convenient to express measures in any of its terms. However, it is more common to use a term which will avoid the use of decimals.

The common units used for measuring length are listed below.

kilometer (km)	1000 meters
hectometer (hm)	100 meters
dekameter (dam)	10 meters
meter (m)	1 meter
decimeter (dm)	0.1 meters
centimeter (cm)	0.01 meters
millimeter (mm)	0.001 meters

AREA

Area measures in the metric system are stated in much the same way as they are with customary measures – in square units. However, square centimeters, square meters, or square kilometers are used instead of square inches or square yards. For very small areas, square millimeters are used.

An area of any size or shape can be measured by finding out how many square units fit into it. For example, consider Figures A and B below.

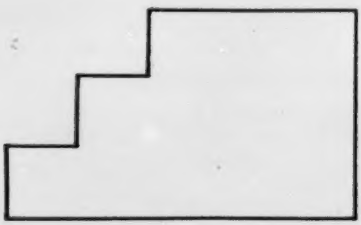


Figure A

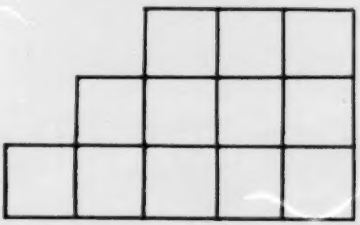


Figure B

If one were to place square centimeters within the boundaries of Figure A, it would be found that 12 square centimeters fill the area, as in Figure B. We would say that the area of the figure is 12 square centimeters or 12 cm^2.

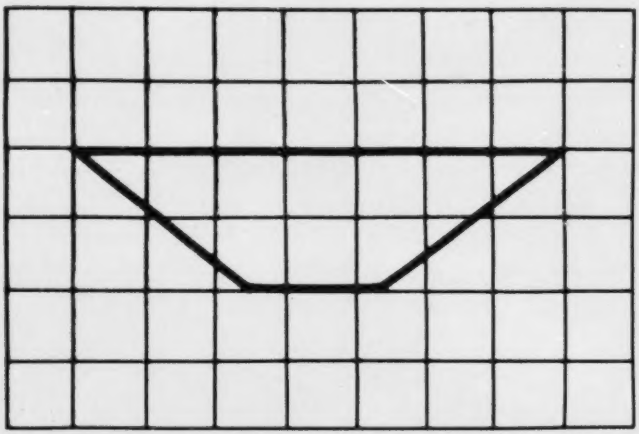


Figure C

For irregularly shaped figures, a centimeter grid could be placed over the figure to estimate the area in square centimeters, as in Figure C.

Other square units include the square millimeter (mm^2), the square decimeter (dm^2), the square dekameter (dam^2), the square hectometer (hm^2), and the square kilometer (km^2).

Smaller items are commonly measured using the square centimeter (cm^2). For example, a small table top measuring 60 cm on each side, is an area of 3600 cm^2. The square meter (m^2) is the common unit of area for measuring fabric, carpeting, floor space, etc. If a room, for example, were 4 meters wide and 5 meters long, the floor space of that room would be 20 square meters or 20 m^2. Extremely large surfaces are measured using the square kilometer (km^2). If a county were rectangular in shape and measured 120 kilometers in one direction and 80 kilometers in the other direction, the area contained within the county would be 9600 km^2.

In the metric system, the term hectare (ha) is used exclusively with land measures. The hectare can be defined as the area of a square of land measuring 100 meters to a side. A hectare of land is about the same amount of land as two and one-half acres in customary measurements. A second term sometimes used with land measures is the term *are*. The are can be defined as the area of a square of land measuring 10 meters on a side.

For measuring land in the United States, the customary acre – which is 43,560 square feet – is used in millions of deeds and other legal documents. For this reason, it is unlikely that this term will go out of existence in the foreseeable future. New land transactions, however, will use metric terms.

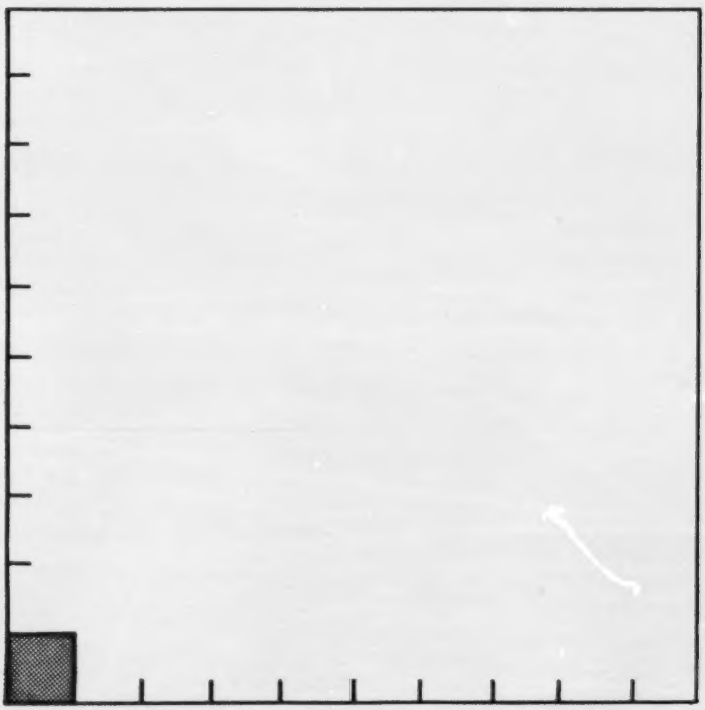


Figure D

Figure D is a square decimeter (dm^2), which measures 10 centimeters on a side, The small shaded square is a square centimeter. It would take

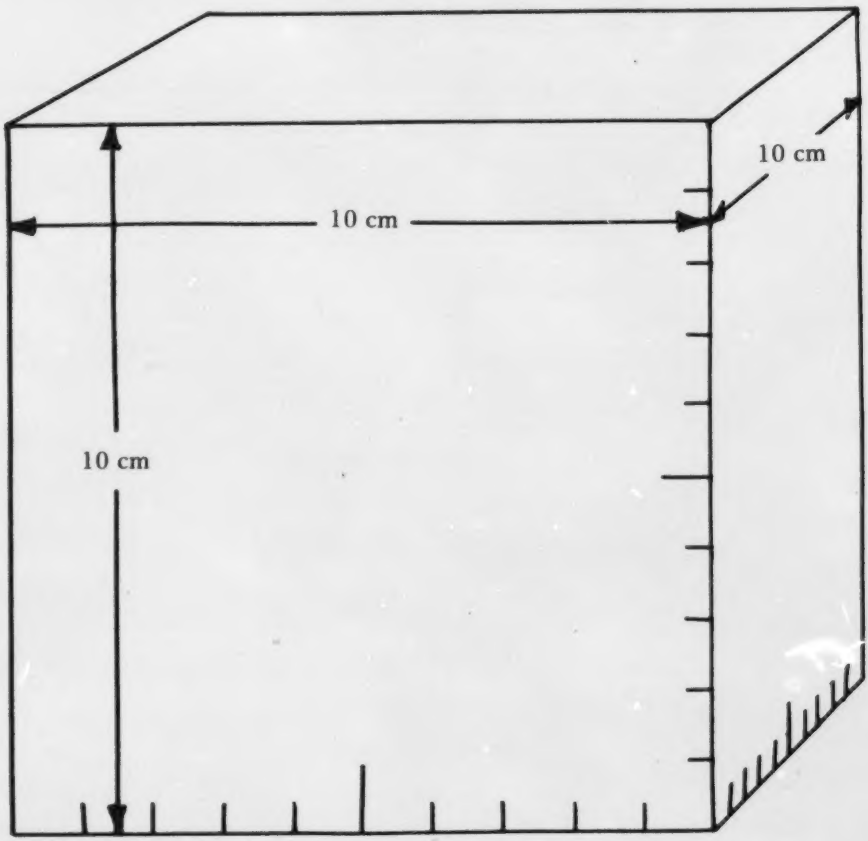
100 of the square centimeters to fill the square decimeter. Thus, we say the area of one square decimeter is 100 square centimeters (1 dm^2 = 100 cm^2). This same relationship exists between square decimeters and square meters (1 m^2 = 100 dm^2), square meters and ares (1 are = 100 m^2), ares and hectares (1 hectare = 100 ares), and hectares and square kilometers (1 km^2 = 100 ha).

The chart below lists terms used in area measure. Note that one hundred is the basic conversion factor for metric units of area.

1 square kilometer (km^2)	=	100 hectares
1 hectare (ha)	=	100 ares
1 are	=	100 square meters
1 square meter (m^2)	=	100 square decimeters
1 square decimeter (dm^2)	=	100 square centimeters
1 square centimeter (cm^2)	=	100 square millimeters

VOLUME

Although not an SI unit, the most widely used unit of volume in the metric system is the liter.



The cube above has faces which are decimeter squares. This cube is called a cubic decimeter (dm^3). It measures 10 centimeters on each side, and it has a capacity of one liter. Liters, of course, can take several different shapes. We find liter containers for juice, milk, soft drinks, etc. A liter is slightly larger than one quart.

The metric prefixes have the same relationship to the liter as they do to the SI base units. However, the most common prefix used with the liter is milli.

The chart below indicates units used for measuring capacity or volume.

1 kiloliter (kL)	1000 liters
1 hectoliter (hL)	100 liters
1 dekaliter (daL)	10 liters
1 liter (L)	1 liter
1 deciliter (dL)	0.1 liters
1 centiliter (cL)	0.01 liters
1 milliliter (mL)	0.001 liters

One cubic centimeter (cm^3) is 0.001 dm^3. Hence, one cubic centimeter has a volume of one milliliter (mL). Very small capacities, such as liquid medicines, are measured in milliliters.

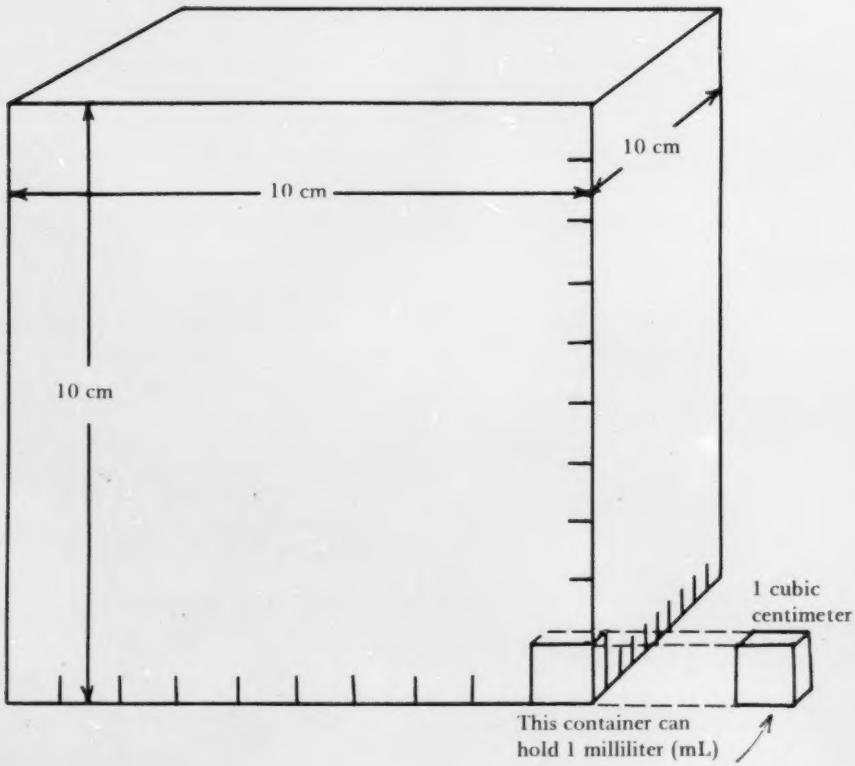
The metric measuring tools which are used for cooking include metric cups and spoons. A set of four measuring cups has capacities of 50, 125, 250, and 500 milliliters. A set of four measuring spoons includes the following:

(approximate)	(exact)
1 tablespoon	15 milliliters
1 teaspoon	5 milliliters
½ teaspoon	2 milliliters
¼ teaspoon	1 milliliter

For most recipes, the difference between metric and nonmetric quantities may be ignored when the ingredients are measured with the same set of measuring tools.

Milk and other liquids are measured in liters (L). An average scrub bucket measures about 10 liters. Larger units of volume are given in cubic meters (m^3) or kililiters (kL).

Volumes of solids are measured in cubic units, such as cubic centimeters (cm^3), cubic decimeters (dm^3), cubic meters (m^3), etc. The volume of any solid shape can be measured by finding out how many cubic units fit into it.



The figure above represents a cubic decimeter, which measures 10 centimeters on each side. The small cube is a cubic centimeter. It would take 1000 of the cubic centimeters to fill the cubic decimeter. Thus, the volume of one cubic decimeter is 1000 cubic centimeters (1 dm^3 = 1000 cm^3). This same relationship exists between cubic millimeters and cubic centimeters (1 cm^3 = 1000 mm^3) and between cubic decimeters and cubic meters (1 m^3 = 1000 dm^3).

The chart below indicates the relationship between volume in cubic units and capacity in liters.

$1\ m^3 = 1000\ dm^3 = 1000\ L$
$1\ dm^3 = 1000\ cm^3 = 1\ L$
$1\ cm^3 = 1000\ mm^3 = 1\ mL$

MASS

Mass is the measure of resistance to change of motion. The mass of an object refers to a measure of the amount of matter in that object. Under ordinary circumstances, mass is a physical constant for a given object. The kilogram (kg) is the base unit for measuring mass.

The term "weight" has been used commonly to mean mass. Technically, however, weight is a measure of the force which gravitation exerts upon a body, equal to mass times acceleration of gravity. In SI, weight in this technical sense is measured by the derived unit "newton" (N).

The common units used for measuring mass are listed below:

kilogram (kg)	1000 grams
hectogram (hg)	100 grams
dekagram (dag)	10 grams
gram (g)	1 gram
decigram (dg)	0.1 grams
centigram (cg)	0.01 grams
milligram (mg)	0.001 grams

The gram (g) has about the same mass as one cubic centimer of water. This can be compared to the mass of a dollar bill. The gram is used for measuring quantities of small mass, such as breakfast cereals or other packaged foods. Though the kilogram is the base unit in SI, one can think of the gram as the base unit for the purpose of using metric prefixes.

The milligram (mg) is an extremely small mass, equal to 0.001 g. In everyday usage, the consumer might encounter the milligram in a pharmacy.

The kilogram has approximately the same mass as one liter of water. It measures about 2.2 pounds. The mass of numerous food items such as vegetables and meat are measured in kilograms. Body weight also is commonly measured in kilograms.

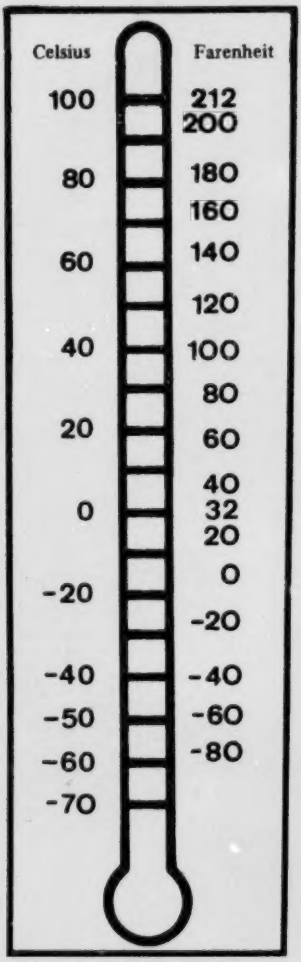
Objects with extremely large mass are measured by the megagram (Mg), commonly called the metric ton. The metric ton is equal to 1000 kilograms and is about 10 percent larger than the customary short ton. If one were to fill a cubic meter with water, the mass would be approximately one metric ton.

TEMPERATURE

The SI base unit of temperature is the kelvin (K). The kelvin scale is based on the scientific principle of absolute zero. On this scale, water freezes at 273.15 °K, body temperature is 310.15 °K, and water boils at 373.15 °K.

However, the Celsius scale (formerly centigrade scale) is for everyday metric use. This scale was developed in 1742 by the Swedish astronomer, Anders Celsius, and it can be derived from the kelvin scale by subtracting 273.15 from the kelvin measure. Thus, on the Celsius scale the freezing point of water is zero degrees and the boiling point of water is 100 degrees. Each degree is 1/100 of the difference between the freezing and boiling points of water.

The thermometer below shows the relationship between degrees Celsius and our customary degrees Fahrenheit.



The following is a guide for commonly used temperatures:

0° C	freezing point of water (32° F)
10° C	moderately cool day (50° F)
25° C	a pleasant spring day (77° F)
30° C	warm summer day (86° F)
37° C	normal body temperature (98.6° F)
40° C	heat wave temperature (104° F)
100° C	boiling point of water (212° F)

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